

## Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement<sup>†</sup>

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*Countries that trade more with each other exhibit higher business cycle correlation. This paper examines the mechanisms underlying this relationship using a large cross-country, industry-level panel dataset of manufacturing production and trade. We show that sector pairs that experience more bilateral trade exhibit stronger comovement. Vertical linkages in production are an important explanation behind this effect: bilateral international trade increases comovement significantly more in cross-border industry pairs that use each other as intermediate inputs. Our estimates imply that these vertical production linkages account for some 30 percent of the total impact of bilateral trade on the business cycle correlation. (JEL E32, F14, F43)*

By almost any measure, the world economy exhibits ever stronger international linkages. International trade tripled as a share of world gross domestic product (GDP) since 1960 (World Trade Organization 2007). This increase is due to a reduction in barriers and a change in the production structure. Goods trade has become more vertical, as intermediates account for an increasing share of total trade (David Hummels, Jun Ishii, and Kei-Mu Yi 2001; Yi 2003).

As economic globalization proceeds apace, what can we say about its effects on international business cycles? The seminal paper by Jeffrey A. Frankel and Andrew K. Rose (1998) established what has become a well-known empirical regularity: country pairs that trade more with each other experience higher business cycle correlation. While the finding has been confirmed by a series of subsequent studies (Todd E. Clark and Eric van Wincoop 2001; Marianne Baxter and Michael A. Kouparitsas 2005; Cesar Calderon, Alberto Chong, and Ernesto Stein 2007), the mechanisms underlying this relationship are still not well understood. Empirically, the key unanswered question is whether the Frankel-Rose result is truly about trade's role in the

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transmission of shocks, it is instead driven by omitted variables: common shocks that happen to be stronger for countries that trade more with each other (Jean Imbs 2004). This question is especially important because standard international business cycle models of transmission have difficulty in matching the empirical results, leading to a “trade-comovement puzzle” (M. Ayhan Kose and Yi 2006). In light of the rapidly changing nature of global trade, understanding these mechanisms is becoming increasingly relevant for economic policy.<sup>1</sup>

This paper uses industry-level data on production and trade to examine the importance of various channels through which international trade affects the aggregate comovement. To carry out the empirical analysis, we combine sectoral output data from the UNIDO database for 55 developed and developing countries during the period 1970–1999 with the bilateral sectoral trade series from the World Trade Database (Robert C. Feenstra et al. 2005). The use of sector-level data has two key advantages. First, the four-dimensional dataset indexed by exporter, importer, and sector-pair permits the inclusion of a rich set of fixed effects in order to control for many possible unobservables and resolve most of the omitted variables and simultaneity concerns in estimation. In particular, country-pair and sector-pair effects can control for aggregate common shocks that plague the interpretation of results based on cross-country data, and provide much more robust evidence on transmission of shocks.

Second, using sector-level data, we investigate whether vertical production linkages across industries can help explain the impact of international trade on comovement. To measure the extent of vertical linkages, we use input-output matrices to gauge the intensity with which individual sectors use each other as intermediate inputs in production. We then condition the impact of bilateral trade on the strength of input-output linkages between each pair of sectors. This provides additional evidence of transmission, by focusing on a particular identifiable channel: the use of intermediate inputs in production.

Our main results can be summarized as follows. First, the Frankel-Rose effect is present at the sector level: sector pairs that experience more bilateral trade exhibit stronger comovement. Second, a given increase in bilateral trade leads to higher comovement in sector pairs that use each other heavily as intermediate inputs. That is, bilateral trade is more important in generating comovement in sectors characterized by greater vertical production linkages. Having established these two results, we then quantify the relative importance of the various channels for aggregate comovement. We write the aggregate correlation as a function of sector-pair level correlations, and carry out the usual thought experiment of increasing bilateral trade between two countries. In order to investigate the relative importance of vertical linkages in generating aggregate comovement, we break down the change in correlation between each individual sector pair into the component that is due to the input-output linkages and the remaining main effect. It turns out that vertical linkages

<sup>1</sup> For instance, Linda L. Tesar (2008) analyzes business cycle synchronization of the European Union (EU) accession countries in a model of cross-border production sharing, and argues that whether trade increases business cycle comovement between Western and Eastern Europe depends crucially on the nature of international trade between the countries in those regions.

explain 32 percent of the overall impact of bilateral trade on aggregate comovement in the full sample of both developed and developing countries.

By breaking down the overall effect into sector-pair level components, we can also evaluate the importance of intra-industry trade in generating increased comovement between trading partners highlighted in recent studies (see, e.g., Jarko Fidrmuc 2004; Jahyeong Koo and William C. Gruben 2006; Calderon, Chong, and Stein 2007). Our methodology lets us decompose the aggregate impact into the part coming from intra-industry comovement (which we call the Within-Sector Component), and the inter-industry comovement (the Cross-Sector Component). The results are surprising. The Within-Sector Component accounts for only 18 percent of the impact of bilateral trade on aggregate business cycle correlation. By contrast, the Cross-Sector Component accounts for the remaining 82 percent of the total effect. What is the intuition for this result? It turns out that the same increase in bilateral trade changes the correlation within a sector by four to five times as much as the correlation across sectors. At first glance, such a difference bodes well for the finding that intra-industry trade is particularly important in generating aggregate comovement. However, a typical sector is quite small in our sample relative to the aggregate. As a result, the impact of a within-sector increase in correlation on the aggregate is moderated by its average small size. Correspondingly, the increase in the correlation of a particular sector with the rest of the economy is that much more important for the same reason: since an average sector is small, its complement is quite large.

Finally, we explore whether the role of trade and vertical linkages differs across subsets of countries. To do this, we split the sample into OECD–OECD country pairs (henceforth, North–North), non-OECD–non-OECD (South–South), and OECD–non-OECD (North–South) country pairs, and carry out the estimation and aggregation exercises on each individual subsample. It turns out that the overall relationship between bilateral trade and comovement is far stronger in the North–North group than the other subsamples, confirming the findings of Calderon, Chong, and Stein 2007. We estimate that the same increase in bilateral trade changes business cycle comovement 4 to 17 times more in the North–North sample compared to the others. By contrast, vertical linkages are relatively more important for North–South trade. While vertical linkages are responsible for 17 percent of the overall impact of trade in the North–North sample, and for 4 percent in the South–South sample, they account for 73 percent of the total among the North–South country pairs.

This paper is part of a growing literature on the role of trade in business cycle transmission. Fidrmuc (2004), Koo and Gruben (2006), and Calderon, Chong, and Stein (2007) find that intra-industry trade, as measured by the Grubel–Lloyd index, accounts for most of the Frankel–Rose effect. Imbs (2004) shows that in addition to bilateral trade, similarity in sectoral structure and financial linkages are also important. By contrast, Baxter and Kouparitsas (2005) find sectoral similarity does not have a robustly significant effect on cross-country output correlations. Our paper is the first to examine both comovement and vertical linkages at the industry level, providing a richer picture of the underlying effects and transmission mechanisms. In particular, the vertical linkage results point to the key role of industrial structure in transmitting shocks via trade. Moreover, our estimates reveal that vertical linkages are especially important within sectors. Thus, our paper arguably

provides a bridge between the results of Imbs (2004) and Baxter and Kouparitsas (2005), by highlighting the interaction between countries' trade and the similarity of their industrial structure in explaining business cycle synchronization. Finally, the evidence on vertical linkages in this paper complements recent DSGE analyses (Kose and Yi 2001; Kose and Yi 2006; Ariel Burstein, Christopher Kurz, and Tesar 2008; Kevin X. D. Huang and Zheng Liu 2007; Costas Arkolakis and Ananth Ramanarayanan 2008) that model these effects.<sup>2</sup>

The rest of the paper is organized as follows. Section I describes the empirical strategy and data. Section II presents the regression results, while Section III describes the quantitative impact of the various channels on aggregate comovement. Section IV concludes.

## I. Empirical Strategy and Data

### A. Sector-Level and Aggregate Comovement

Let there be two economies,  $c$  and  $d$ , each comprised of  $\mathcal{I}$  sectors indexed by  $i$  and  $j$ . The aggregate growth in the two countries,  $y^c$  and  $y^d$ , can be written as:

$$y^c = \sum_{i=1}^{\mathcal{I}} s_i^c y_i^c$$

and

$$y^d = \sum_{j=1}^{\mathcal{I}} s_j^d y_j^d,$$

where  $y_i^c$  is the growth rate of sector  $i$  in country  $c$ , and  $s_i^c$  is the share of sector  $i$  in the aggregate output of country  $c$ . The business cycle covariance between these two countries is then equal to:

$$(1) \quad \text{Cov}(y^c, y^d) = \text{Cov}\left(\sum_{i=1}^{\mathcal{I}} s_i^c y_i^c, \sum_{j=1}^{\mathcal{I}} s_j^d y_j^d\right) = \sum_{i=1}^{\mathcal{I}} \sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \text{Cov}(y_i^c, y_j^d).$$

Since all of the empirical work in this literature is carried out on correlations, and because, conceptually, correlations are pure measures of comovement, we take one extra step and rewrite the identity in terms of correlations:

$$(2) \quad \rho^{cd} = \frac{1}{\sigma^c \sigma^d} \sum_{i=1}^{\mathcal{I}} \sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \rho_{ij}^{cd}.$$

In this expression,  $\sigma^c$  and  $\sigma^d$  are the standard deviations of aggregate growth in the two countries, while  $\sigma_i^c$  and  $\sigma_j^d$  are the standard deviations of the growth rates in individual sectors  $i$  and  $j$  in countries  $c$  and  $d$ , respectively.

<sup>2</sup> Using data on US multinationals, Burstein, Kurz, and Tesar (2008) find that trade between affiliates—the measure of production sharing used in that paper—is robustly correlated to bilateral comovement of manufacturing GDP at the country level.

Until now, the literature has examined the left-hand side of this identity, the correlation of countries' aggregate growth  $\rho^{cd}$ . Using sector-level data, this paper examines the impact of sector-level trade on the correlation between individual sectors in the two economies,  $\rho_{ij}^{cd}$ . As we show in the paper, this allows us to develop a much richer picture of the mechanics of trade's impact on aggregate comovement.

In particular, we estimate the following specification, using comovement and trade data for each sector-pair:

$$(3) \quad \rho_{ij}^{cd} = \alpha + \beta_1 Trade_{ij}^{cd} + \mathbf{u} + \varepsilon_{ij}^{cd}.$$

In the benchmark estimations, the left-hand side variables are correlations computed on 30 years of annual data, helping reduce the measurement error.  $Trade_{ij}^{cd}$  is one of four possible trade intensity measures, constructed as described in Section I.D.

All specifications include various configurations of fixed effects  $\mathbf{u}$ . The observations are recorded at the exporter  $\times$  sector  $\times$  importer  $\times$  sector level, rendering possible the use of a variety of fixed effects. The baseline specifications control for importer, exporter, and sector effects. These capture the average effect of country characteristics on comovement across trading partners and sectors, such as macro policies, country-level aggregate volatility, country size and population, and the level of income. Sector effects capture any inherent characteristics of sectors, including, but not limited to, overall volatility, tradability, capital, skilled and unskilled labor intensity, R&D intensity, tangibility, reliance on external finance, liquidity needs, or institutional intensity. We also estimate the model with exporter  $\times$  sector and importer  $\times$  sector effects. These control for the average comovement properties of each sector within each country across trading partners, for instance tariffs and nontariff barriers. Finally, we also control for country-pair and sector-pair effects. The country-pair effects capture the average linkages for each country pair, such as bilateral distance, total bilateral trade and financial integration, common exchange rate regimes, monetary and fiscal policy synchronization, and sectoral similarity, among others. Sector-pair effects absorb the average comovement for a particular pair of sectors in the data. Note that when we use country-pair effects, the coefficient on trade is identified purely from the variation in bilateral trade volumes *within each country pair across industry pairs*.<sup>3</sup>

Some papers in the literature focus on the impact of intra-industry trade, in particular on the aggregate comovement. A typical finding is that intra-industry trade, captured by the aggregate Grubel-Lloyd index for each country pair, is solely responsible for the result that trade between two countries increases comovement. In order to isolate the impact of intra-industry trade, we estimate a variant of equation (3) that allows the coefficient on the trade variable to differ when it occurs within the industry:

$$(4) \quad \rho_{ij}^{cd} = \alpha + \beta_1 Trade_{ij}^{cd} + \beta_2 \mathbf{1}[i = j] Trade_{ij}^{cd} + \mathbf{u} + \varepsilon_{ij}^{cd},$$

<sup>3</sup>Equation (3) is estimated on the full sample, ignoring the possibility of coefficient heterogeneity across pairs of sectors. As an alternative, an earlier version of the paper estimated a random coefficient model that allows for coefficient heterogeneity. Results were practically identical to the OLS estimates presented below (if anything the average slope coefficient is slightly larger in the random coefficient model). We therefore present OLS estimates in this version of the paper, both for expositional simplicity and because we are ultimately interested in the average impact of trade among all sector pairs.

where  $\mathbf{1}[\cdot]$  is the indicator function. That is, the coefficient on trade can be different for observations in which  $i = j$ .

### B. Vertical Linkages and Transmission of Shocks

We then investigate further the nature of transmission of shocks at the sector level. We would like to understand whether vertical production linkages help explain the positive elasticity of the output correlation—within and across sectors—with respect to trade in a sector. The explanation behind this link relies on the vertical nature of the production chain. Here, a positive shock (either demand or supply) to a sector in one country increases that sector's demand for intermediate goods in production, and thus stimulates output of intermediates in the partner country (Kose and Yi 2001; Burstein, Kurz, and Tesar 2008; Huang and Liu 2007).<sup>4</sup>

We exploit information from the input-output (I-O) matrices about the extent to which sectors use each other as intermediates in production. Our hypothesis is that the positive link between trade and comovement will be stronger in sector pairs that use each other as intermediates in production. To establish this effect, we estimate the following specification:

$$(5) \quad \rho_{ij}^{cd} = \alpha + \beta_1 Trade_{ij}^{cd} + \gamma_1 (IO_{ij} Exports_i^{cd} + IO_{ji} Exports_j^{dc}) + \mathbf{u} + \varepsilon_{ij}^{cd},$$

where  $IO_{ij}$  is the  $(i, j)$ th cell of the I-O matrix. It captures the value of intermediate inputs from sector  $i$  required to produce \$1 of final output of good  $j$ . It is interacted with the trade variable  $Exports_i^{cd}$ , which is the value of exports in sector  $i$  from country  $c$  to country  $d$ . That is, exports of good  $i$  from country  $c$  to country  $d$  will increase comovement by more with sectors  $j$  that use  $i$  heavily as an intermediate. Correspondingly,  $IO_{ji}$  is the value of intermediate  $j$  required to produce \$1 of final good  $i$ . Therefore, comovement between sector  $i$  in country  $c$  and sector  $j$  in country  $d$  will be more affected by exports of  $j$  from  $d$  to  $c$ ,  $Exports_j^{dc}$ , whenever  $i$  uses  $j$  intensively as an intermediate ( $IO_{ji}$  is high). Note that we constrain the coefficient ( $\gamma_1$ ) to be the same regardless of the direction of trade. This is because indices  $c$  and  $d$  are completely interchangeable, so there is no economic or technological reason why the coefficients on  $IO_{ij} Exports_i^{cd}$  and  $IO_{ji} Exports_j^{dc}$  should be different. In addition, the coefficient magnitudes in the unconstrained regressions were quite similar, and the  $F$ -tests could not reject equality in most specifications.

Once again, to focus attention on intra-industry trade, the final specification allows the coefficients to be different when trade is intra-industry:

$$(6) \quad \rho_{ij}^{cd} = \alpha + \beta_1 Trade_{ij}^{cd} + \gamma_1 (IO_{ij}^{cd} Exports_i^{cd} + IO_{ji} Exports_j^{dc}) \\ + \beta_2 \mathbf{1}[i = j] Trade_{ij}^{cd} + \gamma_2 \mathbf{1}[i = j] (IO_{ij} Exports_i^{cd} + IO_{ji} Exports_j^{dc}) \\ + \mathbf{u} + \varepsilon_{ij}^{cd}.$$

<sup>4</sup> See Ramanarayanan (2009) for illustrative evidence that at sector level, comovement of output between the United States and Canada is increasing in the amount of intermediate input trade.



### C. Identification and Interpretation

What is the role of international trade in the transmission of business cycles? Theoretically and quantitatively, the challenge has been to find frameworks and/or parameter values that are consistent with the observed correlations in the data. Empirically, the debate is whether the Frankel-Rose result is truly about trade's role in the transmission of shocks, or it is instead driven by omitted variables: common shocks that happen to be stronger for countries that trade more with each other.

The theoretical and quantitative literature focuses on transmission.<sup>5</sup> In the canonical framework of David K. Backus, Patrick J. Kehoe, and Finn E. Kydland (1995, henceforth BKK), that features one homogeneous good produced by both countries, international trade *lowers* business cycle correlation between countries. In fact, in the baseline BKK (1995) model, the output correlation is negative, even when productivity shocks are positively correlated. The intuition for this is clear: when goods are substitutable, a positive shock in one country leads to more output in that country, but less output in the trading partner, as resources are shifted to the more productive location.

Kose and Yi (2006) model the Frankel-Rose relationship directly. Their main finding is that the qualitative relationship between trade intensity and business cycle correlation can be reproduced in the standard BKK (1995) setup with three countries. However, the model does not perform well quantitatively. The trade-comovement relationship is roughly 10 times weaker in the model than it appears to be in the data.

These authors then demonstrate two ways of improving the match of the model to the data. First, if they assume that trade impacts the correlation of true total factor productivity (TFP) directly, the model can replicate the magnitudes in the data very well. This approach is quite unsatisfying because it is assumed exogenously rather than modeled in a production framework, and thus circumvents any economic mechanism at work. At the same time, it also speaks to the transmission versus common shocks debate in the empirical literature: if trade is correlated with common productivity shocks, then the Frankel-Rose estimates themselves may not be informative about the role of trade in transmission as we discuss below.

Second, Kose and Yi (2006) find that the positive relationship between trade and comovement becomes much stronger under lower elasticity of substitution between domestic and foreign goods. When this elasticity is 0.9—goods from the different countries are complements—instead of the baseline 1.5, the quantitative performance of the model in matching the data improves dramatically.

The elasticity of substitution is thus the key parameter underlying the trade-comovement relationship in quantitative models. Unfortunately, in the canonical BKK (1995) model with aggregate demand linkages, it is difficult to understand what the low elasticity of substitution—indeed, complementarity—between products coming from different countries really represents. After all, available estimates of the elasticity of substitution in consumption based on disaggregated data yield values that are far higher, typically in the range of three to ten (Christian Broda and David E. Weinstein 2006, henceforth BW).

<sup>5</sup> Indeed, one does not need a model to rationalize the trade-business cycle link by appealing to exogenous common shocks hitting countries that trade with each other.

This is why the notion of vertical linkages in production is so important. Indeed, while consumption elasticities tend to be high, it is reasonable to believe that elasticities in production are low. That is, inputs in production are somehow “essential,” in the sense that a negative shock to one input has the potential to severely reduce the ultimate final output. The complementarity view of the production process is influential, most notably associated with Michael Kremer (1993), and recently revived by Charles I. Jones (2007, 2008). This is the approach taken by Burstein, Kurz, and Tesar (2008). These authors model a vertical production structure in which intermediate inputs from the different countries are strong complements, and demonstrate that this assumption can generate both higher levels of output correlations, and a stronger relationship between trade intensity and those correlations.<sup>6</sup>

On the empirical side, ever since Frankel and Rose’s original contribution, the debate has been about whether transmission or common shocks are responsible for business cycle comovement across countries. Taken at face value, the Frankel and Rose result is about transmission. By emphasizing the role of trade linkages, the authors, in effect, argue that shocks in one country—be it to demand or productivity—propagate to another country through trade. Indeed, as detailed above, transmission is at the heart of the theoretical and quantitative literature on international business cycles.

A competing hypothesis is that countries comove simply because their shocks are correlated. An influential proponent of the common shock view is Imbs (2004). This paper argues that country pairs with a similar production structure exhibit greater business cycle synchronization because individual industries are subject to common shocks. Therefore countries that have a similar industrial mix will be more synchronized.<sup>7</sup> In the most stark form, the common shock view has no role for international trade. If industries are truly hit by common global technology or demand shocks, comovement will occur even in the complete absence of trade (and therefore transmission).

What is troubling about this debate is that with country-level data, it is very difficult to sort out the relative importance of the transmission and common shock channels, or estimate either one of them reliably. For instance, the positive relationship between overall bilateral trade and comovement (Frankel and Rose 1998), or between intra-industry trade and comovement (Fidrmuc 2004; Koo and Gruben 2006; Calderon, Chong, and Stein 2007) is not conclusive evidence of transmission, since it could be driven by the omitted common shocks. Countries that are close to each other have high levels of bilateral trade, but their production structure could also be more similar, or their monetary policy could be more coordinated. In this case bilateral trade could be a proxy for greater common shocks rather than transmission. Until now, the strategy adopted in the literature to deal with this estimation problem has been to run a horse

<sup>6</sup> Steve Ambler, Emanuela Cardia, and Christian Zimmermann (2002) and Arkolakis and Ramanarayanan (2008) also build models with two stages and vertical production linkages across countries, and show that quantitatively, adding a second production stage does not help match either the observed levels of GDP correlations across countries, or the observed positive relationship between trade intensity and those correlations, at least with the canonical BKK (1995) elasticity of 1.5. These results are further confirmation that simply assuming two production stages may not be enough. A low elasticity is important for the quantitative performance of these models. Arkolakis and Ramanarayanan (2008)’s quantitative exercise stands in stark contrast with our empirical results, and suggests that another quantitative framework, or at least a much lower elasticity of substitution, is needed to match the data.

<sup>7</sup> This is not the only mechanism through which common shocks can be rationalized. Monetary policy coordination would be another example.



race between the two types explanatory variables and see which is a more robust determinant of comovement (Imbs 2004; Baxter and Kouparitsas 2005).

This paper proposes a different approach. Estimation at the industry level allows us to sweep out many of the potential common shock explanations, and focus on results that are driven by transmission. In particular, inclusion of country-pair effects eliminates any impact of common shocks that occur at the country-pair level, such as similarity in industrial structure, aggregate demand, currency unions or any other type of monetary policy coordination, among many others. In addition, the inclusion of sector (indeed, sector-pair) effects allows us to control for the impact of common global sectoral shocks that are an integral part of the Imbs (2004) explanation of comovement. In order for common shocks to drive our results, they would have to be correlated with trade at the sector-pair level. A large amount of trade in machinery in the United Kingdom and textiles in the United States would have to be a proxy for the prevalence of common demand and/or technology shocks in that pair of sectors, after controlling for the aggregate characteristics of the US-UK country pair and the machinery-textiles the sector pair. It is clear that at the level of individual sector pairs, this omitted variables problem is much less likely to arise.

In addition, the use of I-O matrices to condition the impact of trade on comovement makes it possible to focus even more squarely on transmission by specifying a particular channel, the trade in intermediate inputs. It is quite difficult to imagine a scenario in which bilateral trade at sector-pair level interacted with the I-O linkages is a proxy for a common shock.<sup>8</sup>

Our empirical results are thus relevant to the theoretical and quantitative literature in two respects. First, we demonstrate that transmission, rather than simply exogenous common shocks, does matter. Second, we show that vertical linkages are an important part of the explanation. Thus, modeling efforts that focus on the production structure rather than aggregate demand linkages are likely to be most fruitful. Clearly, for the vertical linkage explanation to have traction, the inputs must be sufficiently essential for the production of the final output that a negative shock to the imported intermediate input leads to a decrease in final output rather than an increase. In that sense, our results offer indirect support for the notion that inputs are essential in production (Kremer 1993; Jones 2007, 2008; Burstein, Kurz, and Tesar 2008).<sup>9</sup>

At the same time, it is important to emphasize that our results cannot be readily mapped back into quantitative models. This is partly because the results in the existing quantitative literature are mostly negative, in the sense that the calibrated models featuring the various plausible mechanisms match neither the level of observed output correlations, nor the elasticity of those correlations with respect to bilateral trade. Thus, there is no natural dominant theory to which our results

<sup>8</sup> The strategy of interacting bilateral sector trade with the input-output matrix can be interpreted as a difference-in-differences model in the spirit of Raghuram G. Rajan and Luigi Zingales (1998). The identifying assumption is that if trade is to matter for the transmission of shocks, it will matter systematically more in sectors technologically characterized by greater input-output linkages. Though we do not emphasize it in the empirical analysis, under this interpretation our estimates can be seen as evidence of the causal impact of trade on comovement.

<sup>9</sup> Unfortunately, greater progress on the issue of complementarities in the production process is currently not possible due to lack of sufficiently detailed production elasticity measures. Nonetheless, below we report a set of preliminary checks using the available elasticity measures that yield sensible conclusions.

can be benchmarked. More importantly, the novel findings in our paper are about variation across sectors rather than aggregate variables. Thus, in order to explore our results in a theoretical setting, a model must feature many sectors and a realistic input-output structure. While such efforts have been undertaken in closed economy settings (John B. Long, Jr. and Charles I. Plosser 1983; Michael Horvath 1998, 2000; Vasco Carvalho 2008), open economy versions of these frameworks have not, to our knowledge, been developed. This type of modeling exercise thus remains a fruitful avenue for future research.

#### D. Data and Summary Statistics

Data on sectoral production come from the UNIDO Industrial Statistics Database. We use the version that reports data according to the 3-digit ISIC Revision 2 classification for the period 1963–2003 in the best cases. There are 28 manufacturing sectors, plus the information on total manufacturing. We dropped observations that did not conform to the standard 3-digit ISIC classification, or took on implausible values, such as a growth rate of more than 100 percent year to year.<sup>10</sup> The resulting dataset is a panel of 55 countries. Though it is unbalanced, the country, sector, and year coverage is reasonably complete in this sample. We calculate correlations of the growth rates of real output in a sector, computed using sector-specific deflators.<sup>11</sup> We then combine information on sectoral production with bilateral sectoral trade flows from the World Trade Database (Feenstra et al. 2005). This database contains trade flows between some 150 countries, accounting for 98 percent of world trade. Trade flows are reported using the 4-digit SITC Revision 2 classification. We convert the trade flows from SITC to ISIC classification and merge them with the production data. The final sample is for the period 1970–1999, giving us three full decades.

We employ four indicators of bilateral trade intensity. Following Frankel and Rose (1998), our measures differ from one another in the scale variable used to normalize the bilateral trade volume. In particular, the first two measures normalize bilateral sectoral trade with output, either at the aggregate or sector level:

$$Trade_{ij}^{cd} = \log \left( \frac{1}{T} \sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{Y_t^c + Y_t^d} \right) \quad (\text{Measure I})$$

$$Trade_{ij}^{cd} = \log \left( \frac{1}{T} \sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{Y_{i,t}^c + Y_{i,t}^d} \right) \quad (\text{Measure II}),$$

<sup>10</sup> The latter is meant to take out erroneous observations, such as those arising from sector re-classifications. It results in the removal of less than 1 percent of yearly observations, and does not affect the results. The coarse level of aggregation into 28 sectors (e.g., food products, apparel, and electrical machinery) makes it highly unlikely that a sector experiences a genuine takeoff of doubling production from year to year.

<sup>11</sup> A previous version of the paper carried out the analysis using the OECD production data from the STAN database. The results were virtually the same as those obtained with the OECD–OECD subsample of the UNIDO database used here, and we do not report them to conserve space.

where  $X_{i,t}^{cd}$  represents the value of exports in sector  $i$  from country  $c$  to country  $d$ ,  $Y_t^c$  is the GDP of country  $c$ , and  $Y_{i,t}^c$  is the output of sector  $i$  in country  $c$  in period  $t$ .

The two alternative intensity measures normalize bilateral sector-level trade volumes by the overall trade in the two countries:

$$Trade_{ij}^{cd} = \log\left(\frac{1}{T} \sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{(X_t^c + M_t^c) + (X_t^d + M_t^d)}\right) \quad (\text{Measure III})$$

$$Trade_{ij}^{cd} = \log\left(\frac{1}{T} \sum_t \frac{X_{i,t}^{cd} + X_{j,t}^{dc}}{(X_{i,t}^c + M_{i,t}^c) + (X_{i,t}^d + M_{i,t}^d)}\right) \quad (\text{Measure IV}),$$

where  $X_{i,t}^c$  ( $M_{i,t}^c$ ) is the total exports (imports) of sector  $i$  of country  $c$ , and  $X_t^c$  is the total manufacturing exports of country  $c$ . In all of our regressions, the intensity measures are averaged over the sample period and their natural logs are used in estimation. In addition, we carried out estimation using the levels of these measures, and the results were robust (see Web Appendix B).<sup>12</sup>

Web Appendix Table A1 reports the list of countries in our sample, the average correlation of manufacturing output between the country and other ones in the sample, and the average of the total manufacturing trade relative to GDP over the sample period. For ease of comparison, we break down the countries into the OECD and non-OECD subsamples. The differences between countries in the business cycle comovement and trade openness are pronounced. The most correlated countries tend to be in Western Europe (Italy, France, Spain), while many of the poorest countries in the sample have an average correlation close to zero or even mildly negative. The share of manufacturing trade in GDP ranges from 8 percent in India to 190 percent in Singapore. Appendix Table A2 reports the average correlations in the North-North, South-South, and North-South subsamples. OECD countries are, on average, considerably more correlated with the other OECD countries (average correlation of 0.397) than non-OECD countries (average of 0.091), while the South-South sample is the least correlated (average 0.065).

Web Appendix Table A3 presents the list of sectors used in the analysis and some descriptive statistics, such as the average correlation of output growth of each sector between country pairs, and the average of the total trade of each sector of a country to its GDP. The average within-sector bilateral correlation, at 0.090, is some 25 percent lower than that of total manufacturing output in the full sample. However, there are also differences in correlations across sectors. For example, the average bilateral correlation of the paper and products sector is around 0.228 while the correlation for the tobacco sector is almost zero. The average cross-sector correlation is 0.068, somewhat lower than the within-sector correlation. There are also large differences in the degree of openness across sectors.

A potential issue in this analysis is that we consider the manufacturing sector only, whereas previous work studied correlations of overall GDP's. We check whether our

<sup>12</sup>The  $Exports_{i,t}^{cd}$  measures used in specifications (5) and (6) and are straightforward modifications of Measures I through IV that use only unidirectional trade, e.g.,  $Exports_{i,t}^{cd} = \log((1/T) \sum_t X_{i,t}^{cd} / (Y_t^c + Y_t^d))$ .

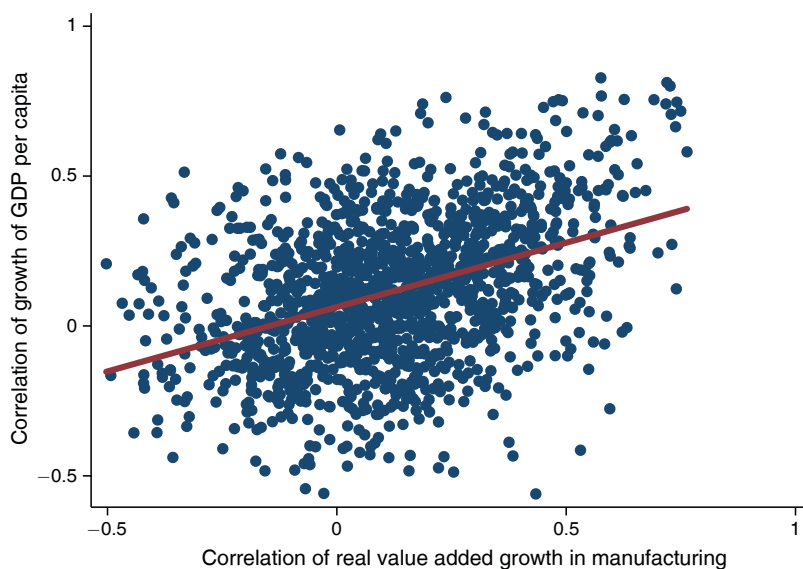


FIGURE 1. CORRELATION OF REAL GDP GROWTH VERSUS CORRELATION OF REAL MANUFACTURING OUTPUT GROWTH

Notes: The x-axis variable is the correlation of manufacturing real output growth between country pairs. The y-axis is the correlation of real GDP growth computed using data from the WDI. In total, there are 1,496 country pairs.

results are informative about the overall business cycle correlations in two ways. First, Figure 1 reports the scatterplot of bilateral GDP correlations against bilateral total manufacturing correlations in our sample. The relationship is positive, with the correlation coefficient of 0.41 and Spearman rank correlation of 0.39. Second, Web Appendix Table A4 reports the canonical Frankel-Rose regression with GDP correlations on the left-hand side, along with a specification that uses manufacturing correlations instead. The two give very similar results, in both the coefficient magnitudes and the  $R^2$ 's. It is clear that by focusing on manufacturing only, we will not reach results that are misleading for the overall economy. Figure 2 reports the scatterplot of bilateral correlations of the total manufacturing output against the four measures of trade openness. As had been found in the large majority of the literature, there is a strong positive association between these variables.

The I-O matrices come from the US Bureau of Economic Analysis. We use the 1997 Benchmark version, and build a Direct Requirements Table at the 3-digit ISIC Revision 2 level from the detailed Make and Use tables and a concordance between the NAICS and the ISIC classifications. As defined by the BEA, the  $(i, j)$ th cell in the Direct Requirements Table gives the amount of a commodity in row  $i$  required to produce one dollar of final output in column  $j$ . From the Direct Requirements Table, we then construct the Total Requirements Table in the standard way.<sup>13</sup> The Total Requirements Table records both the direct requirement (how much textiles

<sup>13</sup> Let  $D$  be the Direct Requirements Table. The Total Requirements Table is then given by:  $T = D[I - D]^{-1}$ , where  $I$  is the identity matrix.

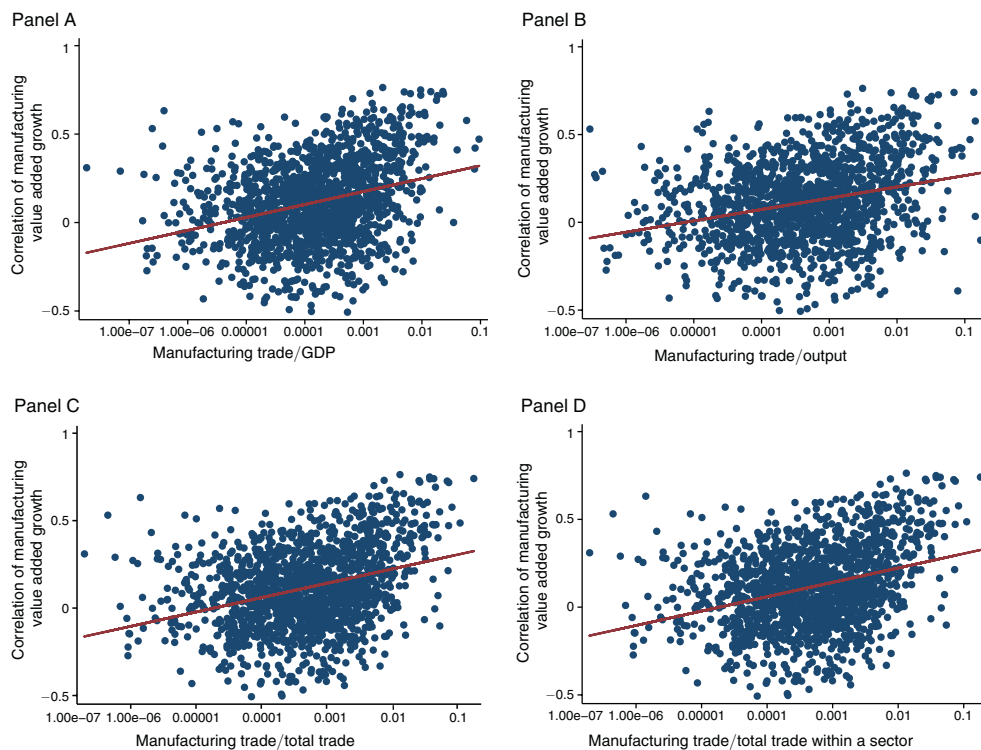


FIGURE 2. CORRELATION OF REAL MANUFACTURING OUTPUT GROWTH VERSUS TRADE RATIOS

*Notes:* The y-axis variable for all figures is the correlation of manufacturing real output growth. The x-axis has a log scale, and variables are: (panel A)  $\text{Log}(\text{Manufacturing Bilateral Trade}/\text{GDP})$ ; (panel B)  $\text{Log}(\text{Manufacturing Bilateral Trade}/\text{Output})$ ; (panel C)  $\text{Log}(\text{Manufacturing Bilateral Trade}/\text{Total Trade})$ ; and (panel D)  $\text{Log}(\text{Manufacturing Bilateral Trade}/\text{Total Trade within a Sector})$ , respectively.

are needed to make one dollar's worth of apparel) as well as the indirect requirements if it takes electrical machinery to make textiles, and textiles in turn are used by apparel, then the apparel sector in effect uses electrical machinery as an input indirectly). By construction, no cell in the Total Requirements Table can take on values greater than one. This is the table we use in estimation.<sup>14</sup>

Figure 3 presents a contour plot of the I-O matrix. Darker shades indicate higher values in the cells of the matrix. Two prominent features stand out. First, the diagonal elements are often the most important. That is, at this level of aggregation, the most important input in a given industry tends to be that industry itself. We will attempt to take this into account in our estimation. Second, outside of the diagonal, the matrix tends to be rather sparse, but there is a great deal of variation in the extent to which

<sup>14</sup> Two points are worth noting about the use of the Total Requirements Table. First, this table records the overall use of intermediate products, rather than of imported intermediates only. Conceptually, we would like to capture the technological requirements of industries, whereas the imports-only I-O table confounds technological requirements with trade policy variation and comparative advantage. It is therefore preferable to use the overall Total Requirements Table. Second, an alternative approach would be to use the Direct Requirements Table. This would be preferable, for instance, if at the business cycle frequencies trade did not affect the indirect input usage due to inventories or lags in production. We carried out the analysis using the Direct Requirements Table, and the results were virtually the same.

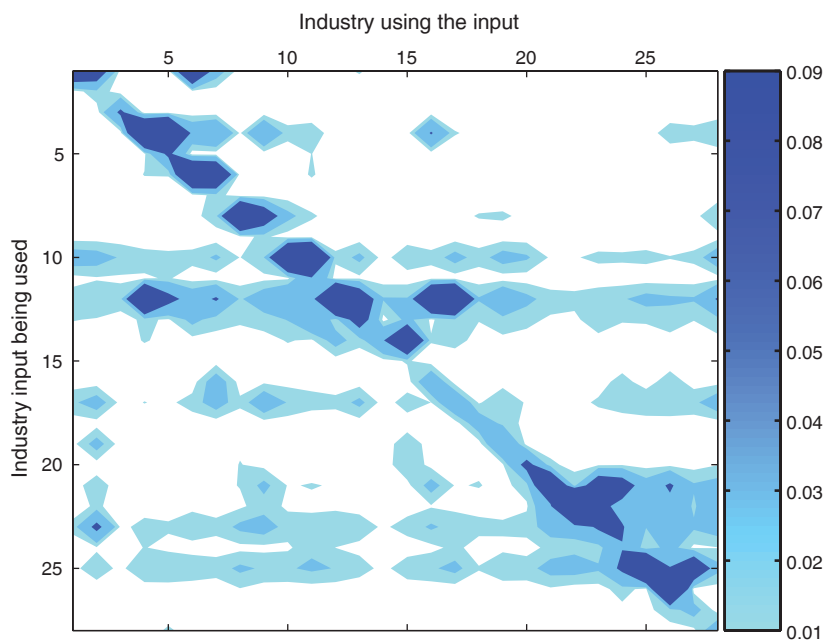


FIGURE 3. CONTOUR REPRESENTATION OF THE BEA INPUT-OUTPUT MATRIX FOR 28 MANUFACTURING SECTORS

*Notes:* The figure represents the Total Requirements Table constructed from the BEA Input-Output data for 28 manufacturing sectors. A darker shade implies that an industry is used by another at a higher rate than an industry-pair with a lighter color. The cut-off rates, from light to dark, are 0.01, 0.03, and 0.09, respectively.

industries use output of other sectors as intermediates. To get a sense of the magnitudes involved, Appendix Table A3 presents, for each sector, the “vertical intensity,” which is the diagonal element of the Total Requirements Table. It is clear that sectors differ a great deal in the extent to which they use themselves as intermediates, with vertical intensity ranging from 0.012 in miscellaneous petroleum and coal products to 0.606 in nonferrous metals. Its mean value across sectors is 0.165. We also present what we call “upstream intensity,” which is the sum of the columns in the I-O matrix (excluding the diagonal term). Upstream intensity captures the total amount of intermediates from other sectors required to produce \$1 of output in each sector. We can see that there is a great deal of variation in this variable as well. It ranges from 0.060 in petroleum refineries to 0.709 in footwear, with a mean of 0.393. Note that, in our estimation, we will exploit variation in the I-O matrix cell-by-cell.

The I-O matrix we use in baseline estimation reflects the input use patterns in the United States. Therefore our approach, akin to Rajan and Zingales (1998), is to treat  $IO_{ij}$  as a technological characteristic of each sector pair, and apply it across countries uniformly. How restrictive is this assumption? Fortunately, we can check this using the GTAP4 database, which contains information on I-O matrices for many countries. We do not use it in the baseline estimations because it contains information on only 17 distinct manufacturing sectors. However, we can use it to check whether the I-O matrices look radically different among the countries in the sample. It turns out that the I-O matrices are quite similar across countries.



For instance, the correlation of the diagonal elements of the I-O matrix (vertical intensity) between the United States and the United Kingdom is 0.91. Taking vertical intensities of the 19 developed countries in the GTAP4 database, the first principal component explains 40 percent of the variation, suggesting that the diagonals of the I-O matrices are quite similar across countries. The same could be said for the upstream intensity, as defined above. The correlation between sector-level upstream intensity between the United States and the United Kingdom, for instance, is 0.75, and the first principal component explains 60 percent of the variation in upstream intensity across the countries in the sample. We estimated all specifications using the average of the I-O matrices across the countries in the sample, and the results were robust.<sup>15</sup>

Finally, we highlight two other features of this I-O matrix: the level of aggregation, and the lack of variation over time. Clearly, I-O matrices can be obtained at a much more disaggregated level. However, in this empirical analysis, we are constrained by the availability of production data. Industry-level output is not available at a more finely disaggregated level for a sufficiently long time period and large enough sample of countries. Regarding the lack of variation over time, it is likely that the relatively coarse level of aggregation is helpful in this regard. Though the finely classified inputs might change over time, the broad production process is relatively more stable. For example, the apparel industry may switch from cotton to synthetic textiles over time. However, the overall amount of textiles used by the apparel sector is unlikely to undergo major changes.

## II. Results

Table 1 presents the results of estimating equation (3). There are four panels, one for each measure of trade linkages. Column (1) reports the simple OLS regression without any fixed effects. Column (2) adds country and sector effects, while column (3) includes country  $\times$  sector effects. Finally, column (4) is estimated using country-pair and sector-pair effects. For ease of reading the tables and to reduce the number of decimal points, the regression coefficients and standard errors reported throughout are multiplied by 1,000 (equivalently, all of the regressors are multiplied by 1/1,000 prior to estimation).

There is a positive relationship between the strength of bilateral sectoral trade linkages and sector-level comovement. Although the trade intensity coefficients tend to become less significant with the inclusion of more stringent fixed effects, they are significant at the 1 percent level in all cases. It is notable that the magnitude of the coefficient is roughly ten times lower than in the aggregate Frankel-Rose specifications. The two specifications are not directly comparable, however, as they capture distinct economic phenomena. In addition, we show below that the estimated sector-level coefficient magnitudes are in fact fully consistent with the estimated aggregate impact.

As we described above, some of the recent literature focuses on the role of intra-industry trade in particular. To isolate whether trade has a special role for within-sector

<sup>15</sup> It is also important to note that the I-O matrix contains information only on intermediate input usage, but not capital or labor, the two factors of production likely to vary the most across countries.

TABLE 1—IMPACT OF TRADE ON COMOVEMENT AT THE SECTOR-LEVEL: POOLED ESTIMATES

|                                                 | Panel A. Trade/GDP         |                   |                   |                   | Panel B. Trade/Output             |                   |                   |                   |
|-------------------------------------------------|----------------------------|-------------------|-------------------|-------------------|-----------------------------------|-------------------|-------------------|-------------------|
|                                                 | (1)                        | (2)               | (3)               | (4)               | (1)                               | (2)               | (3)               | (4)               |
| Trade                                           | 6.64***<br>(0.06)          | 3.06***<br>(0.08) | 2.70***<br>(0.08) | 1.47***<br>(0.09) | 5.79***<br>(0.06)                 | 2.52***<br>(0.07) | 2.20***<br>(0.07) | 0.91***<br>(0.09) |
| Observations                                    | 653,588                    | 653,588           | 653,588           | 653,588           | 650,341                           | 650,341           | 650,341           | 650,341           |
| $R_o^2$                                         | 0.021                      | 0.114             | 0.250             | 0.173             | 0.016                             | 0.114             | 0.251             | 0.173             |
| $R_w^2$                                         | —                          | 0.0024            | 0.0016            | 0.0004            | —                                 | 0.0020            | 0.0014            | 0.0002            |
|                                                 | Panel C. Trade/Total trade |                   |                   |                   | Panel D. Trade/Sector total trade |                   |                   |                   |
|                                                 | (1)                        | (2)               | (3)               | (4)               | (1)                               | (2)               | (3)               | (4)               |
| Trade                                           | 7.56***<br>(0.06)          | 3.19***<br>(0.08) | 2.84***<br>(0.08) | 1.51***<br>(0.09) | 8.08***<br>(0.06)                 | 3.13***<br>(0.08) | 2.90***<br>(0.08) | 1.29***<br>(0.10) |
| Observations                                    | 655,011                    | 655,011           | 655,011           | 655,011           | 655,011                           | 655,011           | 655,011           | 655,011           |
| $R_o^2$                                         | 0.027                      | 0.114             | 0.250             | 0.173             | 0.027                             | 0.114             | 0.250             | 0.173             |
| $R_w^2$                                         | —                          | 0.0027            | 0.0019            | 0.0004            | —                                 | 0.0024            | 0.0020            | 0.0002            |
| $\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$           | N                          | Y                 | N                 | N                 | N                                 | Y                 | N                 | N                 |
| $\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$ | N                          | N                 | Y                 | N                 | N                                 | N                 | Y                 | N                 |
| $\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$ | N                          | N                 | N                 | Y                 | N                                 | N                 | N                 | Y                 |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressor of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair.  $\mu_{c1}$  and  $\mu_{c2}$  are country 1 and 2 fixed effects, respectively.  $\mu_i$  and  $\mu_j$  are sector  $i$  and  $j$  fixed effects, respectively. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

correlations, we estimate equation (4), in which the coefficient on the trade variable is allowed to be different for observations with  $i = j$ . That is, bilateral trade is allowed to affect the correlation of textiles in the United States with textiles in the United Kingdom differently than the correlation of textiles in the United States with apparel (or machinery) in the United Kingdom. Table 2 presents the results. The structure of this table is similar to the previous one, with columns 1–4 differing in the configuration of fixed effects they use. It is clear that the coefficient on the within-sector trade is about 4–5 times the size of the coefficient on cross-sector trade, and always significantly different at the 1 percent level. There is indeed something about the within-sector transmission of shocks through trade. In estimating the next specification, we attempt to understand the sources of this difference, while in the calculation of aggregate impact, we assess its quantitative importance for the aggregate comovement.

*Vertical Production Linkages, Trade, and Comovement.*—Next, we estimate the role of vertical production linkages in explaining comovement within sector pairs. Table 3 presents the results of estimating equation (5). Once again, there are four panels that use different measures of trade intensity. Column (1) reports the simple OLS regression without any fixed effects. Column (2) adds country and sector effects, while column (3) includes country  $\times$  sector effects. Finally, column (4) is estimated using country-pair and sector-pair effects.

TABLE 2—IMPACT OF TRADE ON COMOVEMENT AT THE SECTOR-LEVEL:  
WITHIN- AND CROSS-SECTOR ESTIMATES

|                                                 | Panel A. Trade/GDP         |                     |                     |                   | Panel B. Trade/Output             |                    |                    |                   |
|-------------------------------------------------|----------------------------|---------------------|---------------------|-------------------|-----------------------------------|--------------------|--------------------|-------------------|
|                                                 | (1)                        | (2)                 | (3)                 | (4)               | (1)                               | (2)                | (3)                | (4)               |
| Trade                                           | 6.52***<br>(0.06)          | 2.97***<br>(0.10)   | 2.59***<br>(0.09)   | 1.35***<br>(0.09) | 5.69***<br>(0.06)                 | 2.43***<br>(0.07)  | 2.10***<br>(0.08)  | 0.81***<br>(0.09) |
| Trade × same sector                             | 2.95***<br>(0.31)          | 3.02***<br>(0.29)   | 3.12***<br>(0.26)   | 3.66***<br>(0.30) | 2.75***<br>(0.32)                 | 2.74***<br>(0.29)  | 2.90***<br>(0.27)  | 2.98***<br>(0.29) |
| Same sector                                     | 100.57***<br>(8.57)        | 101.69***<br>(7.81) | 104.19***<br>(7.10) | –                 | 70.30***<br>(5.82)                | 68.64***<br>(5.25) | 71.07***<br>(4.75) | –                 |
| Observations                                    | 653,588                    | 653,588             | 653,588             | 653,588           | 650,341                           | 650,341            | 650,341            | 650,341           |
| $R_o^2$                                         | 0.022                      | 0.115               | 0.251               | 0.173             | 0.017                             | 0.115              | 0.251              | 0.173             |
| $R_w^2$                                         | –                          | 0.0030              | 0.0023              | 0.0006            | –                                 | 0.0025             | 0.0021             | 0.0003            |
|                                                 | Panel C. Trade/Total trade |                     |                     |                   | Panel D. Trade/Sector total trade |                    |                    |                   |
|                                                 | (1)                        | (2)                 | (3)                 | (4)               | (1)                               | (2)                | (3)                | (4)               |
| Trade                                           | 7.44***<br>(0.06)          | 3.09***<br>(0.08)   | 2.72***<br>(0.08)   | 1.39***<br>(0.10) | 7.94***<br>(0.06)                 | 3.01***<br>(0.08)  | 2.77***<br>(0.08)  | 1.15***<br>(0.10) |
| Trade × same sector                             | 3.09***<br>(0.32)          | 3.23***<br>(0.29)   | 3.31***<br>(0.26)   | 3.93***<br>(0.31) | 4.20***<br>(0.35)                 | 3.80***<br>(0.32)  | 3.93***<br>(0.29)  | 3.95***<br>(0.32) |
| Same sector                                     | 93.02***<br>(7.53)         | 95.58***<br>(6.85)  | 97.22***<br>(6.16)  | –                 | 87.14***<br>(5.64)                | 79.04***<br>(5.10) | 80.70***<br>(4.57) | –                 |
| Observations                                    | 655,011                    | 655,011             | 655,011             | 655,011           | 655,011                           | 655,011            | 655,011            | 655,011           |
| $R_o^2$                                         | 0.028                      | 0.115               | 0.251               | 0.173             | 0.027                             | 0.115              | 0.251              | 0.173             |
| $R_w^2$                                         | –                          | 0.0034              | 0.0026              | 0.0007            | –                                 | 0.0031             | 0.0027             | 0.0005            |
| $\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$           | N                          | Y                   | N                   | N                 | N                                 | Y                  | N                  | N                 |
| $\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$ | N                          | N                   | Y                   | N                 | N                                 | N                  | Y                  | N                 |
| $\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$ | N                          | N                   | N                   | Y                 | N                                 | N                  | N                  | Y                 |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressors of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair.  $\mu_{c1}$  and  $\mu_{c2}$  are country 1 and 2 fixed effects, respectively.  $\mu_i$  and  $\mu_j$  are sector  $i$  and  $j$  fixed effects, respectively. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

There is a highly statistically significant relationship between trade intensity interacted with I-O linkages and cross-sector comovement in all specifications. The positive coefficient implies that sector pairs that use each other heavily as intermediates experience a higher elasticity of comovement with respect to bilateral trade intensity. Note also that the main effect of trade remains highly significant. That is, vertical linkages are a significant determinant of comovement as well as of the role of trade in increasing comovement. But they are clearly not the whole story. Section III calculates how much of trade's impact on aggregate comovement can be explained by vertical linkages.

Finally, Table 4 reports estimation results for equation (6). These establish whether the impact of I-O linkages is different for within-sector comovement compared to cross-sector comovement. This might be especially important in light of our earlier observation that the diagonal elements of the I-O matrix tend to be much larger than the off-diagonal elements. The four panels and configurations of

TABLE 3—IMPACT OF TRADE ON COMOVEMENT AT THE SECTOR-LEVEL: VERTICAL LINKAGE ESTIMATES

|                                                 | <i>Panel A. Trade/GDP</i>         |                      |                      |                    | <i>Panel B. Trade/Output</i>             |                     |                     |                    |
|-------------------------------------------------|-----------------------------------|----------------------|----------------------|--------------------|------------------------------------------|---------------------|---------------------|--------------------|
|                                                 | (1)                               | (2)                  | (3)                  | (4)                | (1)                                      | (2)                 | (3)                 | (4)                |
| Trade                                           | 6.23***<br>(0.06)                 | 2.73***<br>(0.08)    | 2.38***<br>(0.09)    | 1.11***<br>(0.10)  | 5.45***<br>(0.06)                        | 2.22***<br>(0.07)   | 1.91***<br>(0.08)   | 0.62***<br>(0.09)  |
| Trade × IO                                      | 14.62***<br>(1.15)                | 15.88***<br>(1.07)   | 15.35***<br>(1.00)   | 17.50***<br>(1.06) | 15.47***<br>(1.15)                       | 14.46***<br>(1.07)  | 13.61***<br>(0.99)  | 14.77***<br>(1.05) |
| Input-Output                                    | 257.45***<br>(14.95)              | 252.13***<br>(13.79) | 244.85***<br>(12.79) | –<br>–             | 218.90***<br>(10.25)                     | 172.87***<br>(9.39) | 165.20***<br>(8.64) | –<br>–             |
| Observations                                    | 653,588                           | 653,588              | 653,588              | 653,588            | 650,341                                  | 650,341             | 650,341             | 650,341            |
| $R_o^2$                                         | 0.022                             | 0.115                | 0.251                | 0.173              | 0.017                                    | 0.115               | 0.251               | 0.173              |
| $R_w^2$                                         | –                                 | 0.0030               | 0.0023               | 0.0006             | –                                        | 0.0025              | 0.0021              | 0.0003             |
|                                                 | <i>Panel C. Trade/Total trade</i> |                      |                      |                    | <i>Panel D. Trade/Sector total trade</i> |                     |                     |                    |
|                                                 | (1)                               | (2)                  | (3)                  | (4)                | (1)                                      | (2)                 | (3)                 | (4)                |
| Trade                                           | 7.14***<br>(0.06)                 | 2.82***<br>(0.08)    | 2.50***<br>(0.09)    | 1.12***<br>(0.10)  | 7.70***<br>(0.07)                        | 2.70***<br>(0.08)   | 2.52***<br>(0.09)   | 0.87***<br>(0.11)  |
| Trade × IO                                      | 15.53***<br>(1.16)                | 17.27***<br>(1.08)   | 15.93***<br>(1.00)   | 19.12***<br>(1.07) | 18.89***<br>(1.21)                       | 20.24***<br>(1.13)  | 18.38***<br>(1.05)  | 19.62***<br>(1.10) |
| Input-Output                                    | 238.14***<br>(12.97)              | 238.14***<br>(11.97) | 223.10***<br>(11.02) | –<br>–             | 240.32***<br>(9.76)                      | 204.28***<br>(8.95) | 189.77***<br>(8.24) | –<br>–             |
| Observations                                    | 655,011                           | 655,011              | 655,011              | 655,011            | 655,011                                  | 655,011             | 655,011             | 655,011            |
| $R_o^2$                                         | 0.028                             | 0.115                | 0.251                | 0.173              | 0.029                                    | 0.115               | 0.251               | 0.173              |
| $R_w^2$                                         | –                                 | 0.0038               | 0.0030               | 0.0009             | –                                        | 0.0035              | 0.0032              | 0.0008             |
| $\mu_{c1} + \mu_{c2} + \mu_i + \mu_j$           | N                                 | Y                    | N                    | N                  | N                                        | Y                   | N                   | N                  |
| $\mu_{c1} \times \mu_i + \mu_{c2} \times \mu_j$ | N                                 | N                    | Y                    | N                  | N                                        | N                   | Y                   | N                  |
| $\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$ | N                                 | N                    | N                    | Y                  | N                                        | N                   | N                   | Y                  |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressors of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair.  $\mu_{c1}$  and  $\mu_{c2}$  are country 1 and 2 fixed effects, respectively.  $\mu_i$  and  $\mu_j$  are sector  $i$  and  $j$  fixed effects, respectively. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

fixed effects are the same as in the previous table. The results here are somewhat ambiguous. Though the within-sector coefficient is still significantly greater than the cross-sector coefficient, the inclusion of I-O linkages reduces this difference in half. That is, once the intermediate input linkages are taken into account—and these tend to be more important with within-sector observations—the elasticity of comovement with respect to trade becomes much more similar for intra- and inter-industry observations.

Our empirical strategy rests in part on the variation in the I-O coefficients across sector pairs. However, another important characteristic of sector pairs that should affect the trade-comovement relationship is the elasticity of substitution between goods in consumption or inputs in production. As discussed in detail in Section I.C, in sector pairs with higher elasticity of substitution, greater trade will raise comovement by less (indeed, it may even make it negative). In Table 5, we examine this possibility, using two types of elasticities. The first comes from Tuan A. Luong (2008), which to our knowledge is the only study that estimates, for each sector, the

TABLE 4—IMPACT OF TRADE ON COMOVEMENT AT THE SECTOR-LEVEL:  
VERTICAL LINKAGES, WITHIN- AND CROSS-SECTOR ESTIMATES

|                                                 | Panel A. Trade/GDP         |                        |                        |                     | Panel B. Trade/Output             |                        |                        |                     |
|-------------------------------------------------|----------------------------|------------------------|------------------------|---------------------|-----------------------------------|------------------------|------------------------|---------------------|
|                                                 | (1)                        | (2)                    | (3)                    | (4)                 | (1)                               | (2)                    | (3)                    | (4)                 |
| Trade                                           | 6.22****<br>(0.06)         | 2.68****<br>(0.08)     | 2.34****<br>(0.09)     | 1.09****<br>(0.10)  | 5.39****<br>(0.06)                | 2.17****<br>(0.08)     | 1.87****<br>(0.08)     | 0.60****<br>(0.09)  |
| Trade ×<br>same sector                          | 0.72<br>(0.49)             | 1.47****<br>(0.46)     | 1.61****<br>(0.42)     | 1.87****<br>(0.48)  | 1.07*<br>(0.48)                   | 1.48****<br>(0.45)     | 1.80****<br>(0.41)     | 1.59****<br>(0.46)  |
| Trade × IO                                      | 13.85****<br>(1.73)        | 18.24****<br>(1.65)    | 16.59****<br>(1.58)    | 17.01****<br>(1.62) | 18.41****<br>(1.71)               | 17.22****<br>(1.63)    | 15.17****<br>(1.55)    | 15.02****<br>(1.58) |
| Trade × same<br>sector × IO                     | -0.76<br>(2.83)            | -7.56****<br>(2.63)    | -6.25**<br>(2.41)      | -5.32**<br>(2.66)   | -7.96****<br>(2.82)               | -8.50****<br>(2.61)    | -7.62****<br>(2.39)    | -5.63**<br>(2.60)   |
| Same sector<br>× IO                             | -100.01****<br>(37.38)     | -147.00****<br>(34.36) | -130.26****<br>(31.22) | -                   | -167.77****<br>(24.94)            | -120.69****<br>(22.85) | -112.44****<br>(20.62) | -                   |
| Same sector                                     | 36.31****<br>(13.68)       | 59.37****<br>(12.66)   | 63.11****<br>(11.57)   | -                   | 29.36****<br>(8.75)               | 43.59****<br>(8.06)    | 48.95****<br>(7.31)    | -                   |
| Input-Output                                    | 291.95****<br>(22.37)      | 293.00****<br>(21.21)  | 271.44****<br>(20.08)  | -                   | 303.27****<br>(15.29)             | 210.03****<br>(14.54)  | 191.79****<br>(13.60)  | -                   |
| Observations                                    | 653,588                    | 653,588                | 653,588                | 653,588             | 650,341                           | 650,341                | 650,341                | 650,341             |
| $R_o^2$                                         | 0.023                      | 0.115                  | 0.251                  | 0.173               | 0.019                             | 0.115                  | 0.252                  | 0.174               |
| $R_w^2$                                         | -                          | 0.0036                 | 0.0029                 | 0.0009              | -                                 | 0.0030                 | 0.0026                 | 0.0005              |
|                                                 | Panel C. Trade/Total trade |                        |                        |                     | Panel D. Trade/Sector total trade |                        |                        |                     |
|                                                 | (1)                        | (2)                    | (3)                    | (4)                 | (1)                               | (2)                    | (3)                    | (4)                 |
| Trade                                           | 7.12****<br>(0.06)         | 2.77****<br>(0.08)     | 2.45****<br>(0.09)     | 1.09****<br>(0.10)  | 7.68****<br>(0.07)                | 2.64****<br>(0.08)     | 2.47****<br>(0.09)     | 0.84****<br>(0.11)  |
| Trade ×<br>same sector                          | 0.82<br>(0.49)             | 1.57****<br>(0.46)     | 1.87****<br>(0.42)     | 2.01****<br>(0.49)  | 2.60****<br>(0.55)                | 2.04****<br>(0.51)     | 2.51****<br>(0.46)     | 2.00****<br>(0.50)  |
| Trade × IO                                      | 15.03****<br>(1.74)        | 20.11****<br>(1.66)    | 17.36****<br>(1.58)    | 19.16****<br>(1.63) | 18.13****<br>(1.81)               | 22.97****<br>(1.73)    | 19.18****<br>(1.64)    | 19.99****<br>(1.67) |
| Trade × same<br>sector × IO                     | -1.37<br>(2.85)            | -8.62****<br>(2.65)    | -7.37****<br>(2.41)    | -6.64**<br>(2.69)   | -7.62**<br>(3.03)                 | -11.03****<br>(2.82)   | -9.54****<br>(2.56)    | -7.17****<br>(2.75) |
| Same sector<br>× IO                             | -105.32****<br>(32.55)     | -144.88****<br>(29.90) | -131.50****<br>(26.91) | -                   | -162.09****<br>(24.22)            | -126.87****<br>(22.22) | -114.57****<br>(19.98) | -                   |
| Same sector                                     | 37.61**<br>(12.05)         | 56.78****<br>(11.15)   | 63.59****<br>(10.04)   | -                   | 47.18****<br>(8.67)               | 47.65****<br>(7.98)    | 54.50****<br>(7.16)    | -                   |
| Input-Output                                    | 275.20****<br>(19.36)      | 279.50****<br>(18.34)  | 249.28****<br>(17.22)  | -                   | 300.51****<br>(14.63)             | 236.30****<br>(13.87)  | 207.01****<br>(12.96)  | -                   |
| Observations                                    | 655,011                    | 655,011                | 655,011                | 655,011             | 655,011                           | 655,011                | 655,011                | 655,011             |
| $R_o^2$                                         | 0.028                      | 0.115                  | 0.251                  | 0.173               | 0.029                             | 0.115                  | 0.251                  | 0.173               |
| $R_w^2$                                         | -                          | 0.0039                 | 0.0032                 | 0.0010              | -                                 | 0.0037                 | 0.0033                 | 0.0008              |
| $\mu_{c1} + \mu_{c2} + \mu_i$<br>+ $\mu_j$      | N                          | Y                      | N                      | N                   | N                                 | Y                      | N                      | N                   |
| $\mu_{c1} \times \mu_i + \mu_{c2}$<br>× $\mu_j$ | N                          | N                      | Y                      | N                   | N                                 | N                      | Y                      | N                   |
| $\mu_{c1} \times \mu_{c2} + \mu_i$<br>× $\mu_j$ | N                          | N                      | N                      | Y                   | N                                 | N                      | N                      | Y                   |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressors of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair.  $\mu_{c1}$  and  $\mu_{c2}$  are country 1 and 2 fixed effects, respectively.  $\mu_i$  and  $\mu_j$  are sector  $i$  and  $j$  fixed effects, respectively. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

TABLE 5—IMPACT OF TRADE ON COMOVEMENT AT THE SECTOR-LEVEL: VERTICAL LINKAGES AND ELASTICITIES OF SUBSTITUTION ESTIMATES

|                                                 | <i>Panel A. Trade/GDP</i>         |                    | <i>Panel B. Trade/Output</i>             |                    |
|-------------------------------------------------|-----------------------------------|--------------------|------------------------------------------|--------------------|
|                                                 | (1)                               | (2)                | (1)                                      | (2)                |
| Trade                                           | 4.92***<br>(0.38)                 | 2.15***<br>(0.12)  | 3.17***<br>(0.37)                        | 1.50***<br>(0.11)  |
| Trade × IO                                      | 15.24***<br>(1.09)                | 17.30***<br>(1.07) | 12.66***<br>(1.07)                       | 14.63***<br>(1.05) |
| Trade × (production elasticity)                 | -2.25***<br>(0.22)                | -                  | -1.56***<br>(0.21)                       | -                  |
| Trade × (consumption elasticity)                | -                                 | -0.17***<br>(0.01) | -                                        | -0.14***<br>(0.01) |
| Observations                                    | 541,386                           | 653,588            | 539,597                                  | 650,341            |
| $R_o^2$                                         | 0.195                             | 0.174              | 0.195                                    | 0.174              |
| $R_w^2$                                         | 0.0010                            | 0.0013             | 0.0005                                   | 0.0008             |
|                                                 | <i>Panel C. Trade/Total trade</i> |                    | <i>Panel D. Trade/Sector total trade</i> |                    |
|                                                 | (1)                               | (2)                | (1)                                      | (2)                |
| Trade                                           | 4.94***<br>(0.38)                 | 2.43***<br>(0.12)  | 4.69***<br>(0.40)                        | 2.21***<br>(0.13)  |
| Trade × IO                                      | 16.83***<br>(1.09)                | 18.89***<br>(1.08) | 17.30***<br>(1.12)                       | 19.35***<br>(1.10) |
| Trade × (production elasticity)                 | -2.26***<br>(0.22)                | -                  | -2.33***<br>(0.23)                       | -                  |
| Trade × (consumption elasticity)                | -                                 | -0.21***<br>(0.01) | -                                        | -0.22***<br>(0.01) |
| Observations                                    | 542,604                           | 655,011            | 542,604                                  | 655,011            |
| $R_o^2$                                         | 0.195                             | 0.174              | 0.195                                    | 0.174              |
| $R_w^2$                                         | 0.0011                            | 0.0016             | 0.0009                                   | 0.0015             |
| $\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$ | Y                                 | Y                  | Y                                        | Y                  |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressors of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair. Production Elasticity taken from Luong (2008), and Consumption Elasticity taken from Broda and Weinstein (2006).  $\mu_{c1}$  and  $\mu_{c2}$  are country 1 and 2 fixed effects, respectively.  $\mu_i$  and  $\mu_j$  are sector  $i$  and  $j$  fixed effects, respectively. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

elasticity of substitution among intermediate inputs in that sector. The second is the elasticity of substitution in consumption among varieties within an individual sector, from BW (2006).<sup>16</sup>

<sup>16</sup> We must emphasize that neither of these measures are exactly what we need. What would be required to control for the complementarity/substitutability issue fully is to have information on the elasticity of substitution between every pair of sectors (in production or consumption). Then, we could condition the impact of trade on the correlation between a pair of sectors on the elasticity of substitution between those two sectors. Unfortunately, pairwise elasticities do not exist. Luong's estimates impose the same elasticity of substitution on all intermediate inputs in each sector. Thus, in the apparel industry, for instance, inputs of textiles have the same elasticity of substitution as inputs of machinery. As such, we cannot exploit variation within a final output sector across intermediate input sectors. BW (2006) compute elasticities in consumption among varieties in a sector. Thus, the BW (2006) elasticity for apparel will reflect the substitution between different varieties of apparel, rather than substitution between apparel and textiles, or apparel and machinery. Thus, in a sector-pair-level regression, the BW (2006) elasticities are even less appropriate than Luong's (2008), because unlike Luong's, they do not have any cross-sector content.



The four panels in Table 5 use the four measures of trade openness. Each specification is estimated controlling for country-pair and sector-pair effects. Column 1 reports the specification in which sector-level trade is interacted with the Luong (2008) elasticity, while column 2 interacts trade with the BW (2006) elasticity.<sup>17</sup> We can see that neither the main effect of bilateral trade nor the interaction of the trade variable with the I-O linkage is affected by the inclusion of the elasticity of substitution as an additional control. Intriguingly, for all the shortcomings of these elasticity measures, the sign of the coefficients goes in the direction predicted by theory. Greater trade increases comovement by *less* in sectors with *higher* elasticities of substitution.

Another aspect of our empirical strategy that deserves attention is the decision to use the log of bilateral trade rather than the level in estimation. The reason we chose the log specification as our baseline is that the trade ratios in levels are extremely skewed, and thus a tiny share of the top values of the trade ratios affect the estimated coefficient a great deal. Appendix B discusses the levels versus logs issue in detail, and reports the full set of estimates using levels rather than logs. All of the main results are robust to estimation in levels. To further assess robustness of these results, Appendix Table A5 repeats the analysis above for correlations computed on HP-filtered data rather than on growth rates. It is evident from these tables that the results are by and large the same when using HP-filtered data.

### III. The Impact of Sector-Level Trade on Aggregate Comovement

The preceding section estimates the impact of bilateral sectoral trade on sector-level comovement, focusing in particular on two aspects of this relationship: intra-industry trade and intermediate input linkages. In this section, we use these estimates to quantify the relative importance of each of these on aggregate comovement.

The identity in equation (2) relates the correlation of aggregate output growth  $\rho^{cd}$  between two countries  $c$  and  $d$  to the correlations  $\rho_{ij}^{cd}$  between each pair of individual sectors  $i$  and  $j$  in those two countries. A change in these bilateral sector-pair correlations leads to the change in the aggregate correlation equal to:

$$(7) \quad \Delta\rho^{cd} = \frac{1}{\sigma^c \sigma^d} \sum_{i=1}^{\mathcal{I}} \sum_{j=1}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \Delta\rho_{ij}^{cd}.$$

As we note in Section I,  $\sigma^c$  and  $\sigma^d$  are the standard deviations of the aggregate manufacturing growth in countries  $c$  and  $d$ ;  $\sigma_i^c$  and  $\sigma_j^d$  are the standard deviations of the growth rate of individual sectors in each economy; and  $s_i^c$  and  $s_j^d$  are the shares of sectors  $i$  and  $j$  in aggregate output of countries  $c$  and  $d$ , respectively. Since aggregate correlation is simply additive in all of the bilateral sector-pair correlations, this expression is an exact one rather than an approximation.

The empirical analysis above estimates the impact of bilateral trade on  $\rho_{ij}^{cd}$ . Thus, we can compute the change in the aggregate volatility brought about by a symmetric

<sup>17</sup> Since the elasticity of substitution varies at the sector level only, the main effect is absorbed by sector-pair effects.

increase in bilateral trade between these two countries. According to the estimates of the baseline equation (3),

$$(8) \quad \Delta\rho_{ij} = \beta_1 \Delta Trade_{ij}^{cd}.$$

The value of  $\Delta Trade_{ij}^{cd}$  corresponds to moving from the twenty-fifth to the seventy-fifth percentile in the distribution of bilateral trade intensity in the sample. This is equivalent to going from the level of bilateral manufacturing trade as a share of GDP of 0.004 percent (Bolivia-Mexico) to 0.07 percent (United States-Indonesia). The thought experiment is a symmetric rise in bilateral trade in all sectors for a given country pair. Thus, the exercise is meant to capture mainly the consequences of cross-sectional variation in bilateral trade intensity between countries, and maps most precisely to the existing literature, which examines aggregate trade and correlations. Note that since the trade variables are taken in logs, we are evaluating the impact of an identical proportional increase in trade in all sectors, rather than an absolute increase.

Plugging  $\Delta\rho_{ij}$  from equation (8) in place of  $\Delta\rho_{ij}^{cd}$  in equation (7) yields the corresponding change in the aggregate correlation between each country pair,  $\Delta\rho^{cd}$ . Note that this comparative static is carried out under two assumptions. The first is that the change in bilateral trade we consider here does not affect sector-level and aggregate volatilities ( $\sigma_i^c$ 's and  $\sigma^c$ 's). This assumption may not be innocuous if, for example, bilateral trade for a given country-pair also represents a large share of total trade for one or both countries. If the change in bilateral trade is large enough to substantially affect the overall trade openness, di Giovanni and Levchenko (2009) show that it will affect both industry-level and aggregate volatility. However, in our sample of countries, it is rarely the case that bilateral trade between any pair of countries accounts for a substantial share of the country's overall trade. In addition, the regression models include various combinations of country and sector-level fixed effects that absorb the trade-volatility relationship at the country level. The second assumption is that bilateral trade does not affect the similarity of the two countries' industrial structure (i.e., the  $s_i^c s_j^d$  terms). A previous version of the paper estimated this effect and found it to be quantitatively tiny, so we do not treat it here. The result that the impact of bilateral trade on sectoral similarity is small has also been reported by Imbs (2004). Though these two channels do not appear to be quantitatively important, they must be kept in mind when interpreting our comparative statics. To be precise, the results below report the impact of bilateral trade on aggregate comovement *due exclusively to changes in sector-pair level comovement*.

We report the mean value of  $\Delta\rho^{cd}$  across all of the country pairs in our data in the first row of Table 6. Note that this calculation gives different values across country pairs because we use actual values of  $s_i^c$ ,  $s_j^d$ ,  $\sigma_i^c$ ,  $\sigma_j^d$ ,  $\sigma^c$ , and  $\sigma^d$  for each country and sector in this calculation. The standard deviations of aggregate and sector-level growth rates are computed over the entire sample period, 1970–1999, and the shares of sectors in total output are averages over the same period. On average in this sample, the standard deviation of aggregate manufacturing output is  $\bar{\sigma}^c = \bar{\sigma}^d = 0.0518$ , while the average standard deviation of a sector is  $\bar{\sigma}_i^c = \bar{\sigma}_j^d = 0.1208$ . The mean share of an individual sector in total manufacturing is  $\bar{s}_i^c = \bar{s}_j^d = 0.034$ . Since this calculation uses an estimated coefficient  $\beta_1$ , the table reports the mean of the

TABLE 6—IMPACT OF TRADE ON AGGREGATE COMOVEMENT:  
BASELINE AND WITHIN VERSUS CROSS-SECTOR ESTIMATES

| Specification                                         | Total effect     | Cross-sector component | Within-sector component |
|-------------------------------------------------------|------------------|------------------------|-------------------------|
| <i>Baseline: Pooled</i>                               |                  |                        |                         |
| $\Delta\rho^{cd}$                                     | 0.031<br>(0.002) | —<br>—                 | —<br>—                  |
| <i>Separate within- and cross-sector coefficients</i> |                  |                        |                         |
| $\Delta\rho^{cd}$                                     | 0.033<br>(0.002) | 0.0268<br>(0.0019)     | 0.0060<br>(0.0004)      |
| Share of total                                        |                  | 0.82                   | 0.18                    |

*Notes:* Calculations based on specification (4), panel A of Tables 1 and 2, respectively. The independent variable is Trade/GDP, and country-pair and sector-pair fixed effects are included. The first row corresponds to the cross-country average impact given by equation (7), while the second row corresponds to the average given by equation (10). Robust standard errors are in parentheses.

standard error of this estimate in parentheses. Not surprisingly, because  $\beta_1$  is highly statistically significant, the change in the aggregate correlation implied by our estimates is highly significant as well.

Our calculation implies that in response to moving from the twenty-fifth to the seventy-fifth percentile in bilateral trade openness, aggregate correlation increases by 0.031, which is equivalent to 0.14 standard deviations of aggregate correlations found in the sample. How does the total effect we obtain by adding up the changes in individual sector-pair correlations compare to the change in comovement obtained from the aggregate Frankel-Rose regression for the manufacturing sector? Using the estimates in column (1) of Appendix Table A4, we calculate that the same change in bilateral trade when applied to these estimates results in an increase in bilateral correlation of 0.046. This implies that our procedure captures about two-thirds of the magnitude implied by the aggregate relationship. Note that there is no inherent reason that these two sets of estimates should match perfectly, as the sector-pair-level estimation uses a much more stringent array of fixed effects than is possible in the canonical Frankel-Rose regression.

The more interesting results concern the relative importance of within- and cross-sector trade in the total estimated impact of trade reported above. To that end, we use the coefficient estimates in equation (4) to break down the change in correlation depending on whether trade occurs in the same sector or not:

$$(9) \quad \Delta\rho_{ij} = \beta_1 \Delta Trade_{ij}^{cd}$$

$$\Delta\rho_{ii} = (\beta_1 + \beta_2) \Delta Trade_{ij}^{cd}.$$

Combining these expressions with equation (7), we decompose the overall effect of trade openness on comovement into the Within-Sector Component and the Cross-Sector Component:

$$(10) \quad \Delta\rho^{cd} = \underbrace{\frac{1}{\sigma^c \sigma^d} \sum_{i=1}^{\mathcal{I}} s_i^c s_i^d \sigma_i^c \sigma_i^d \Delta\rho_{ii}}_{\text{Within-Sector Component}} + \underbrace{\frac{1}{\sigma^c \sigma^d} \sum_{i=1}^{\mathcal{I}} \sum_{j \neq i}^{\mathcal{I}} s_i^c s_j^d \sigma_i^c \sigma_j^d \Delta\rho_{ij}}_{\text{Cross-Sector Component}}$$

The second row of Table 6 reports the results. The Within-Sector Component contributes only about 0.006 to increased aggregate correlation, accounting for about 18 percent of the total estimated effect. The Cross-Sector Component contributes the remaining 82 percent. These results are that much more striking because the estimated coefficient on within sector trade,  $(\beta_1 + \beta_2)$ , is four to five times the magnitude of the cross-sector trade,  $\beta_1$ . Nonetheless, the within-sector trade accounts for only a small minority of the total impact. This goes against the conclusions of aggregate-level studies such as Koo and Gruben (2006), or Calderon, Chong, and Stein (2007) that argue for the importance of intra-industry trade for aggregate comovement. If intra-industry trade matters, we demonstrate that it is not because it increases comovement within the same sectors. What is the intuition for this result? Our estimates show that bilateral trade between two countries increases comovement both within sectors and across sectors. However, a typical individual sector is quite small relative to the economy. As we report above, the typical share of an individual sector in total output is less than 4 percent. Thus, there is limited scope for the increased correlation between, say, the textile sector in the United States and the textile sector in the United Kingdom to raise aggregate comovement. However, we also find that more trade in textiles raises the correlation between textiles in the United States and every other sector in the United Kingdom. Since the sum of all other sectors except textiles is quite large, the cross-sector correlation has much greater potential to increase aggregate comovement.<sup>18</sup>

We now move on to the role of vertical production linkages and bilateral trade in generating comovement between countries. Using our estimates of equation (5), a given change in trade openness produces the following change in sector-pair correlation:

$$(11) \quad \Delta\rho_{ij} = \beta_1 \Delta Trade_{ij}^{cd} + \gamma_1 (\text{IO}_{ij} + \text{IO}_{ji}) \Delta Trade_{ij}^{cd}.$$

Note that in this case, even though we apply the same change in trade openness,  $\Delta Trade_{ij}^{cd}$ , to each sector pair  $ij$ , the actual resulting change in correlation will be different across sector pairs, due to input-output linkages  $\text{IO}_{ij}$  and  $\text{IO}_{ji}$ . With this in mind, we decompose the total estimated effect of trade on aggregate comovement into what we call the main effect and the vertical linkage effect:

$$(12) \quad \Delta\rho^{cd} = \underbrace{\frac{1}{\sigma^c \sigma^d} \sum_{i=1}^I \sum_{j=1}^I s_i^c s_j^d \sigma_i^c \sigma_j^d \beta_1 \Delta Trade_{ij}^{cd}}_{\text{Main Effect}} + \underbrace{\frac{1}{\sigma^c \sigma^d} \sum_{i=1}^I \sum_{j=1}^I s_i^c s_j^d \sigma_i^c \sigma_j^d (\text{IO}_{ij} + \text{IO}_{ji}) \gamma_1 \Delta Trade_{ij}^{cd}}_{\text{Vertical Linkage Effect}}.$$

<sup>18</sup> One might be concerned that the reason we get a small impact of intra-industry comovement on the aggregate is that we study a change in trade that is the same for within- and cross-sector pairs, while in the data most trade could be intra-industry. In our exercise, it is actually not possible to consider a change in intra-industry trade that would be different from a change in cross-industry trade. This is because an increase in sector  $i$  exports from

TABLE 7—IMPACT OF TRADE ON AGGREGATE COMOVEMENT:  
MAIN EFFECT VERSUS VERTICAL LINKAGE ESTIMATES

| Specification                                         | Total effect     | Main effect             |                        | Vertical linkage effect |                        |
|-------------------------------------------------------|------------------|-------------------------|------------------------|-------------------------|------------------------|
| <i>Baseline: Pooled</i>                               |                  |                         |                        |                         |                        |
| $\Delta\rho^{cd}$                                     | 0.035<br>(0.002) | 0.023<br>(0.002)        |                        | 0.011<br>(0.001)        |                        |
| Share of total                                        |                  | 0.68                    |                        | 0.32                    |                        |
| <i>Separate within- and cross-sector coefficients</i> |                  |                         |                        |                         |                        |
|                                                       |                  | Within-sector component | Cross-sector component | Within-sector component | Cross-sector component |
| $\Delta\rho^{cd}$                                     | 0.035<br>(0.002) | 0.0035<br>(0.0006)      | 0.0217<br>(0.0019)     | 0.0032<br>(0.0006)      | 0.0061<br>(0.0006)     |
| Share of total                                        |                  | 0.10                    | 0.63                   | 0.09                    | 0.18                   |

*Notes:* Calculations based on specification (4), panel A of Tables 3 and 4, respectively. The independent variable is Trade/GDP, and country-pair and sector-pair fixed effects are included. The first row corresponds to the cross-country average impact given by equation (12), while the second row breaks down the average impact into Within- and Cross-Sector Components. Robust standard errors are in parentheses.

The results are reported in the first row of Table 7. The estimates of equation (5) imply that the change in bilateral trade we are considering raises aggregate comovement by about 0.035, which is slightly larger than 0.031 obtained from estimates of equation (3). Applying the reported average standard errors, it turns out that this difference is not statistically significant, however. More interestingly, our estimates show that the vertical linkage effect accounts for 32 percent of the total impact of increased bilateral trade on aggregate comovement, with the remaining 68 percent due to the main effect.

Finally, we can break down the main and the vertical linkage effects into the Within- and the Cross-Sector Components using our estimates of equation (6). The last row of Table 7 reports the results. What is remarkable is how different the behavior of the two effects in within- and cross-sector observations are. Above, we found that the Within-Sector Component accounts for 18 percent of the total impact of trade on aggregate volatility. By contrast, the Within-Sector Component accounts for 34 percent of the vertical linkage effect (0.003 out of 0.009). Not surprisingly, since the diagonal elements of the I-O matrix tend to be large, there is more scope for vertical transmission of shocks through within-industry trade. Indeed, in this set of estimates, just the Within-Sector Component of the vertical linkage effect on its own accounts for 9 percent of the total increase in comovement, accounting for half of the 18 percent implied by equation (4). Nonetheless, the lion share of the total impact (63 percent) is accounted by the cross-sector, main effect.

*Heterogeneity across Country Pairs.*—Tables 6 and 7 report the mean impact of trade openness on aggregate volatility in our sample of country pairs. But the change in aggregate correlation is calculated for each country pair, and depends on country-pair characteristics. What can we say about the variation in the estimated

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country  $c$  to country  $d$  changes  $Trade_{ii}^{cd}$ , but also  $Trade_{ij}^{cd}$  for every other sector  $j$ . Economically, this means that we must allow for, and estimate, the impact of an increase in exports in sector  $i$  not only on the within-sector correlation  $\rho_{ii}$ , but also the cross-sector correlation  $\rho_{ij}$  for every  $j$ .

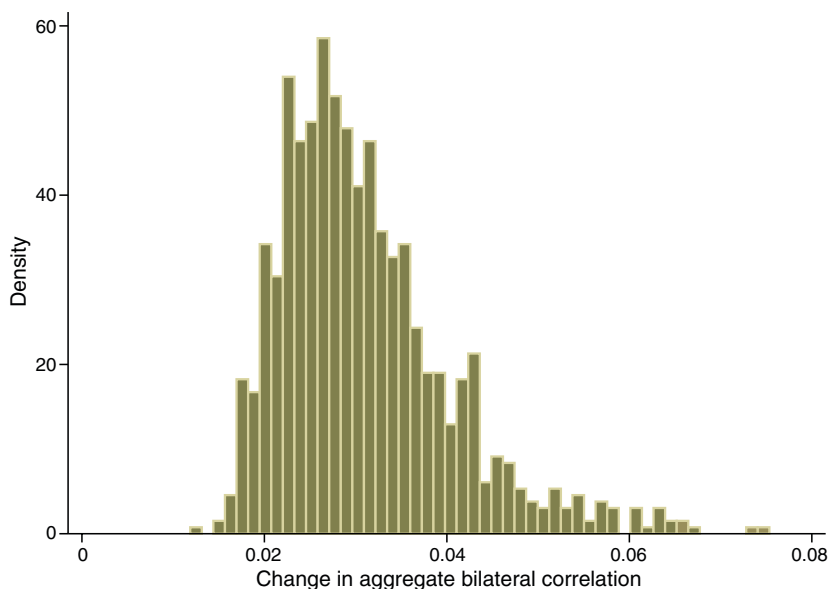


FIGURE 4. IMPACT OF TRADE ON BILATERAL AGGREGATE CORRELATION  
ACROSS COUNTRY PAIRS

*Notes:* This figure reports the histogram of the impact of a change in bilateral trade intensity on aggregate bilateral correlation for the country pairs in the sample. Calculations are based on specification (4) in Table 1, and correspond to the magnitude calculations in the first row of Table 6.

impact across countries? In the remainder of this section, we explore this question in two ways.

First, Figure 4 reports the histogram of estimated impacts of bilateral trade on aggregate comovement. There is significant variation across country pairs, with the change in correlation ranging from 0.012 to 0.075. Half of the observations are fairly close to the mean impact of 0.031 reported in Table 6: the twenty-fifth percentile impact is 0.024, and the seventy-fifth percentile is 0.036. What can we say about the relative importance of the vertical transmission channel in this sample? It turns out that among country pairs in our sample, the share of the overall impact due to the vertical transmission channel ranges from 18 to 46 percent (the mean, reported above, is 32 percent). The twenty-fifth to seventy-fifth range is much narrower, however, from 30 to 34 percent. Thus, the relative importance of the vertical transmission channel does not appear to vary that much across country pairs.

The discussion above reveals the variation in the estimated impact of trade as it depends on country characteristics. However, it uses the same full-sample coefficient estimates for each country pair. Thus, it ignores the possibility that the impact of international trade itself differs across country samples. To check for this, we re-estimated the specifications in this paper on three subsamples: North-North, in which both trading partners are OECD countries; South-South, in which both partners are non-OECD countries, and finally North-South. Table 8 reports the results of estimating equations (3) through (6) comparing the three subsamples side-by-side. We only report the specifications that use our preferred configuration



TABLE 8—IMPACT OF TRADE ON COMOVEMENT FOR COUNTRY-PAIR SUBSAMPLES: ALL SPECIFICATIONS

|                                                 | Specification A    |                       |                   | Specification B    |                       |                   |
|-------------------------------------------------|--------------------|-----------------------|-------------------|--------------------|-----------------------|-------------------|
|                                                 | OECD/<br>OECD      | Non-OECD/<br>non-OECD | OECD/<br>non-OECD | OECD/<br>OECD      | Non-OECD/<br>non-OECD | OECD/<br>non-OECD |
|                                                 | (1)                | (2)                   | (3)               | (1)                | (2)                   | (3)               |
| Trade                                           | 5.69***<br>(0.27)  | 1.23***<br>(0.20)     | 0.23***<br>(0.12) | 5.49***<br>(0.27)  | 1.21***<br>(0.20)     | 0.17***<br>(0.12) |
| Trade $\times$ same sector                      | –                  | –                     | –                 | 6.07***<br>(0.76)  | 0.48***<br>(0.65)     | 2.07***<br>(0.43) |
| Observations                                    | 141,188            | 144,883               | 367,517           | 141,188            | 144,883               | 367,517           |
| $R_o^2$                                         | 0.251              | 0.132                 | 0.130             | 0.252              | 0.132                 | 0.130             |
| $R_w^2$                                         | 0.0032             | 0.0003                | 1.10E-05          | 0.0037             | 0.0003                | 0.0001            |
|                                                 | Specification C    |                       |                   | Specification D    |                       |                   |
|                                                 | OECD/<br>OECD      | Non-OECD/<br>non-OECD | OECD/<br>non-OECD | OECD/<br>OECD      | Non-OECD/<br>non-OECD | OECD/<br>non-OECD |
|                                                 | (1)                | (2)                   | (3)               | (1)                | (2)                   | (3)               |
| Trade                                           | 5.17***<br>(0.28)  | 1.19***<br>(0.20)     | 0.08<br>(0.12)    | 5.15***<br>(0.28)  | 1.17***<br>(0.20)     | 0.11<br>(0.12)    |
| Trade $\times$ same sector                      | –                  | –                     | –                 | 2.01*<br>(1.12)    | 0.81<br>(1.10)        | 0.81<br>(0.69)    |
| Trade $\times$ IO                               | 33.75***<br>(2.88) | 1.5922<br>(2.20)      | 7.66***<br>(1.45) | 31.80***<br>(5.00) | 2.39<br>(3.34)        | 4.39**<br>(2.13)  |
| Trade $\times$ same sector $\times$ IO          | –                  | –                     | –                 | –3.63<br>(6.99)    | –3.88<br>(5.68)       | 3.13<br>(3.67)    |
| Observations                                    | 141,188            | 144,883               | 367,517           | 141,188            | 144,883               | 367,517           |
| $R_o^2$                                         | 0.252              | 0.132                 | 0.130             | 0.252              | 0.132                 | 0.130             |
| $R_w^2$                                         | 0.0042             | 0.0003                | 0.0001            | 0.0042             | 0.0003                | 0.0001            |
| $\mu_{c1} \times \mu_{c2} + \mu_i \times \mu_j$ | Y                  | Y                     | Y                 | Y                  | Y                     | Y                 |

Notes: Robust standard errors in parentheses.  $R_o^2$  is the overall  $R^2$ , and  $R_w^2$  is the within- $R^2$  associated with the regressors of interest. The sample period is 1970–1999. The dependent variable is the correlation of the real output growth between sector  $i$  and sector  $j$  of the country pair. In all specifications, the trade variable is normalized by GDP. All specifications include country-pair and sector-pair fixed effects. Variable definitions and sources are described in detail in the text.

\*\*\*Significant at the 1 percent level.

\*\*Significant at the 5 percent level.

\*Significant at the 10 percent level.

of fixed effects: country-pair and sector-pair. The impact of international trade, as well as the relative importance of the vertical transmission channel differ a great deal between subsamples. These estimates reveal that both are primarily a phenomenon relevant to the North-North trade. Table 9 summarizes the aggregate impact of an identical change in bilateral trade in the three subsamples. For comparability, we consider an identical increase in bilateral trade in the three subsamples, which is the same as in the calculations above. The results are striking. Moving from the twenty-fifth to the seventy-fifth percentile in bilateral trade openness raises business cycle correlation by 0.114 in the North-North sample, a number that is more than three times larger than the full sample estimate. By contrast, trade leads to an increase in correlation of 0.028 in the South-South sample, and a tiny 0.007 in the North-South sample. The relative importance of vertical linkages is very different as well. For North-North trade, vertical linkages are responsible for only 17 percent of the total impact, well below the 32 percent full sample figure. For South-South trade, this channel is even less important,

TABLE 9—IMPACT OF TRADE ON AGGREGATE COMOVEMENT FOR SUBSAMPLES:  
MAIN EFFECT VERSUS VERTICAL LINKAGE ESTIMATES

|                   | OECD/OECD         |             |                         |
|-------------------|-------------------|-------------|-------------------------|
|                   | Total effect      | Main effect | Vertical linkage effect |
| $\Delta\rho^{cd}$ | 0.114             | 0.095       | 0.019                   |
|                   | (0.005)           | (0.005)     | (0.002)                 |
| Share of total    |                   | 0.83        | 0.17                    |
|                   | Non-OECD/non-OECD |             |                         |
|                   | Total effect      | Main effect | Vertical linkage effect |
| $\Delta\rho^{cd}$ | 0.028             | 0.026       | 0.001                   |
|                   | (0.004)           | (0.004)     | (0.002)                 |
| Share of total    |                   | 0.96        | 0.04                    |
|                   | OECD/non-OECD     |             |                         |
|                   | Total effect      | Main effect | Vertical linkage effect |
| $\Delta\rho^{cd}$ | 0.007             | 0.002       | 0.005                   |
|                   | (0.003)           | (0.003)     | (0.001)                 |
| Share of total    |                   | 0.27        | 0.73                    |

Notes: Calculations based on specification C of Table 8. The independent variable is Trade/GDP, and country and sector-pair fixed effects are included. The row corresponds to the cross-country average impact given by equation (12). Robust standard errors are in parentheses.

accounting for just 4 percent of the total. By contrast, vertical linkages account for 73 percent of the total impact of trade in the North-South sample.

To summarize, the picture that emerges from this analysis is a nuanced one. On the one hand, the overall impact of trade is far larger in the North-North group of countries than elsewhere. On the other hand, vertical linkages are relatively less important there, compared to the North-South trade.

#### IV. Conclusion

This paper studies the mechanisms behind a well-known empirical regularity: country pairs that trade more with each other experience higher business cycle comovement. We start by estimating the impact of trade on comovement not just for each pair of countries, but for each pair of sectors within each pair of countries. It turns out that bilateral trade increases comovement at the sector level as well. Next, we investigate the possible transmission channels behind this result. We exploit the information contained in input-output tables on the extent to which sectors use others as intermediate inputs, to demonstrate the importance of the vertical transmission channel. The robust finding is that sector pairs that use each other as intermediates exhibit significantly higher elasticity of comovement with respect to trade.

We then go on to quantify the relative importance of the various channels through which trade generates aggregate comovement. Though previous literature identified intra-industry trade as especially important in propagating shocks across countries, we find that the increase in within-sector correlation due to trade accounts for only about 18 percent of the overall impact, the rest being due to transmission across sectors. When it comes to vertical linkages, we find that they account for 32 percent of the impact of bilateral trade on aggregate comovement.

How should we interpret these results? On the one hand, the evidence on vertical linkages accords well with the recent quantitative studies that model transmission of shocks through production chains (Burstein, Kurz, and Tesar 2008; Huang and Liu 2007). On the other hand, we find that some 70 percent of the overall estimated impact is still “unexplained” by vertical linkages. Developing a theoretical and quantitative framework that can be used to fit the industry-level facts uncovered in this paper presents a fruitful direction for future research.

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